Status of Power and Propulsion Element (PPE) for Gateway

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NAC HEO Committee Meeting
August 27, 2018

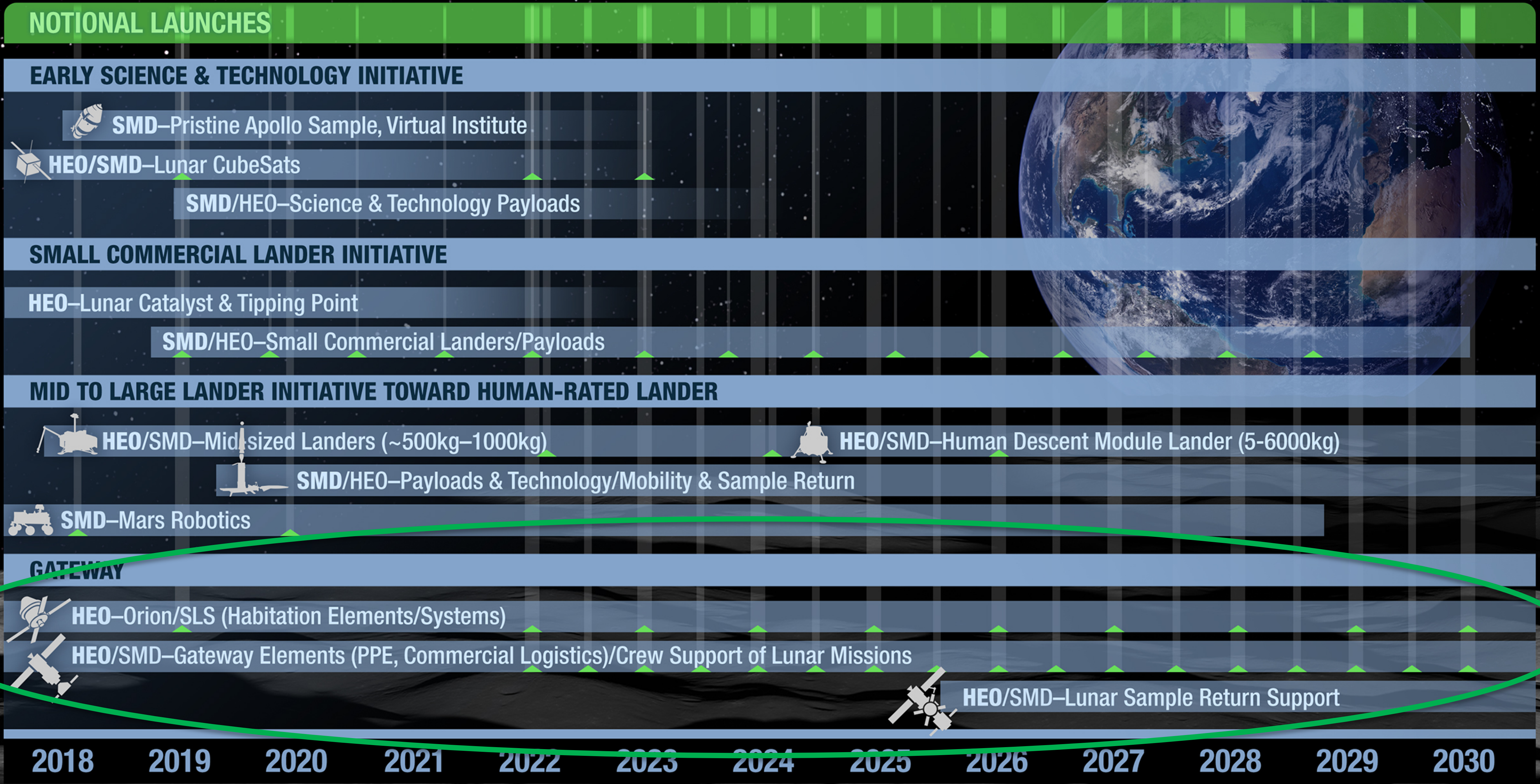
Summary of Previous Update to NAC HEOC

- **Advantages of solar electric propulsion in cislunar space and extensibility to higher power systems.**
- **A power and propulsion element (PPE) in planning as the first element in a cislunar gateway concept.**
- **Industry partnership studies through NextSTEP Broad Agency Announcement (BAA) Appendix C. Five industry study contracts completed 23 March 2017.**
- **PPE Sources Sought Notice released 30 Nov 2017.**
  - Sources sought notice refers to a potential PPE design, development, build, and flight demonstration with contemplated future use on NASA missions
  - Potential industry/NASA partnership for development and spaceflight demonstration of spacecraft capabilities, including advanced solar electric propulsion, communications, and controls
  - Strategy to stimulate and utilize U.S. commercial space industry while leveraging those same commercial capabilities through partnerships and future contracts to deliver NASA mission capabilities

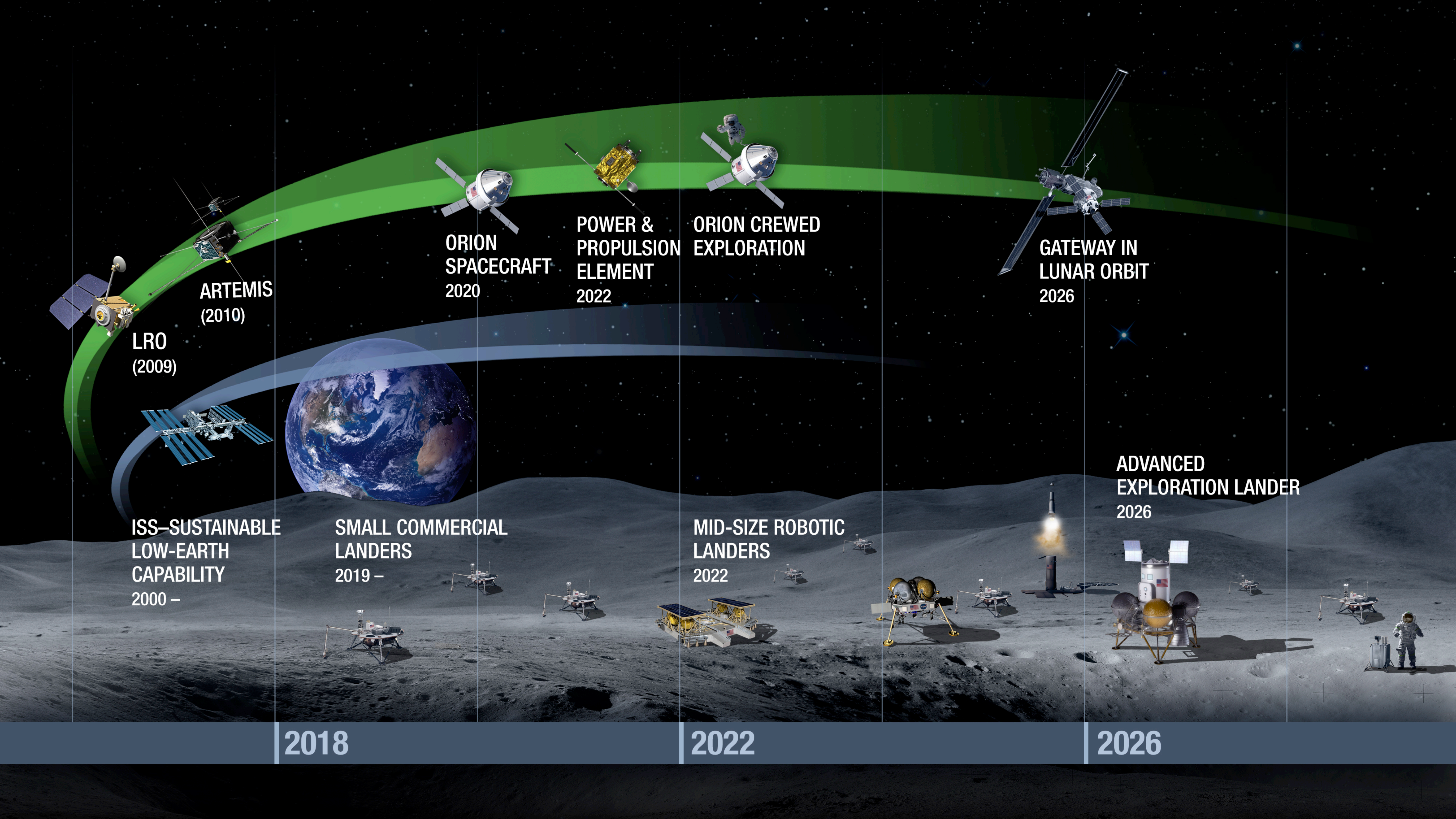
PPE Near Term Milestones Completed
as of Aug 21, 2018

✓PPE NASA performance requirements refinement close	Apr 5, 2018
✓Support international interactions on gateway plan	Apr 10-13, 2018
✓International Space Development Conference panel participation	May 24, 2018
✓Release of Draft Solicitation for Spaceflight demonstration of a PPE	June 21, 2018
✓PPE Industry Day	July 10, 2018
✓AIAA Propulsion and Energy Forum panel participation	July 11, 2018
✓Industry comments due on draft BAA	July 20, 2018
✓AAS/AIAA Astrodynamics Specialist Conference presentations	Aug 19-23, 2018

NASA EXPLORATION CAMPAIGN



Timelines are tentative and will be developed further in FY 2019

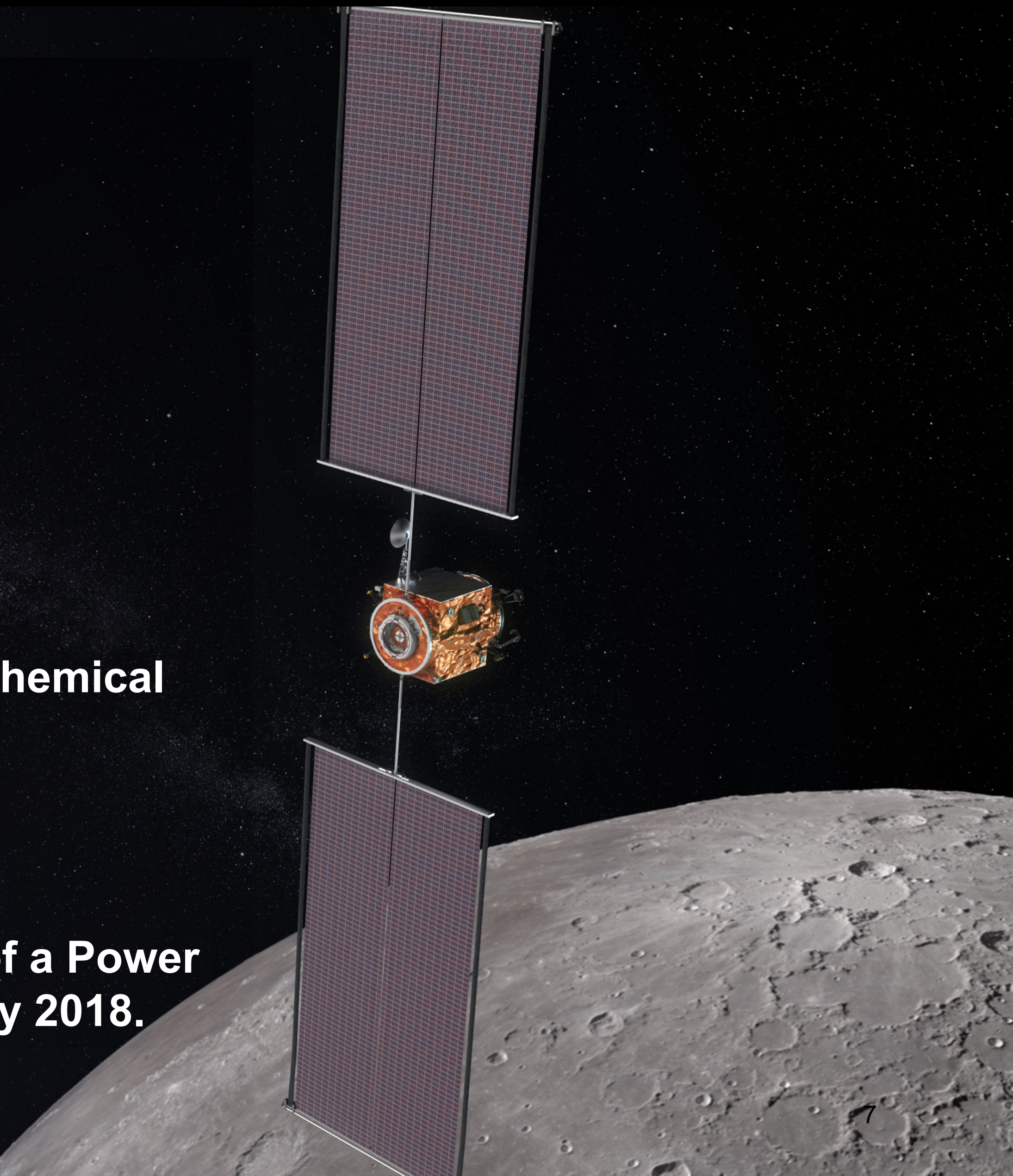

LRO
(2009)
ARTEMIS
(2010)
ORION
SPACECRAFT
2020
POWER &
PROPULSION
ELEMENT
2022
ORION CREWED
EXPLORATION
GATEWAY IN
LUNAR ORBIT
2026
ISS–SUSTAINABLE
LOW-EARTH
CAPABILITY
2000 –
SMALL COMMERCIAL
LANDERS
2019 –
MID-SIZE ROBOTIC
LANDERS
2022
ADVANCED
EXPLORATION LANDER
2026
2018
2022
2026

Approach to Power and Propulsion Element Development

- **PPE leverages advanced solar electric propulsion (SEP) technology development and demonstration formulation:**
  - First Gateway element capability targeted for launch readiness in 2022
  - Leverage with U.S. industry current capabilities and future plans for future use of SEP
  - Developed through public-private partnership
  - Spaceflight demonstration of advanced solar electric propulsion spacecraft for industry and NASA objectives
  - Also provides for communications, and transportation, controls, power to future Gateway elements

Power and Propulsion Element:
First Module in Lunar Orbit for Gateway

- 2022 launch on partner-provided commercial rocket
- 50 kW class spacecraft with 40 kW class EP system
- Power transfer to other gateway elements
- Passive docking using IDSS compliant interface
- Capability to move gateway to multiple lunar orbits
- Orbit control for gateway stack
- Communications with Earth, visiting vehicles, and initial communications support for lunar surface systems
- 2t class xenon EP propellant capacity, refuelable for both chemical and xenon propellants
- Accommodations for utilization payloads
- 15 year life
- NASA issued a synopsis for a Spaceflight Demonstration of a Power and Propulsion Element in Feb. 2018. Draft BAA issued July 2018. Final BAA expected Sept. 6, 2018

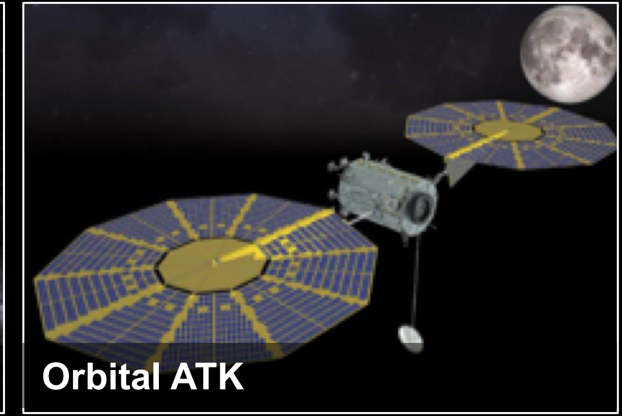


Power and Propulsion Element Industry Studies

NextSTEP Appendix C: Issued Aug 11, 2017 | Selections announced Nov. 1, 2017

- U.S. industry-led studies for an advanced solar electric propulsion (SEP) vehicle capability.
- Four-month studies commenced late Nov 2017.

Boeing



Orbital ATK

Lockheed Martin

Sierra Nevada Corporation, Aerojet Rocketdyne, Draper

SSL, DSS, Draper, University of Illinois-Urbana Champaign

PPE Requirements Development

- **NASA has provided, as part of the BAA, only its unique requirements defining the specific functionality that PPE will provide as the first element of the Gateway**
  - Allows industry the ability to propose a bus and spacecraft that also meets their needs for future commercial spacecraft applications

- **Offerors will propose a preliminary full-set of PPE Flight System requirements (including the NASA-unique requirements) with the their proposals**

Spacecraft Demonstration of a Power and Propulsion Element Draft Broad Agency Announcement (DBAA) 80GRC018R0005, Released 21 June 2018

Description of Effort: The DBAA seeks creative and innovative proposals from industry for the spaceflight demonstration of one or more PPE(s) through a public-private partnership to meet the desired objectives and performance requirements of both partners.

- **The development of the PPE capabilities will be based on:**
  - Joint industry/gov’t objectives and requirements
  - Advanced solar electric propulsion and other NASA functionality
  - Leverages the demonstrated reliability of commercial spacecraft
  - Offeror proposed launch capability on a commercial launch vehicle
  - Flight by September 2022
- **Partner will own PPE through ~1 year spaceflight demonstration with an option for NASA to subsequently own and use the inflight asset(s) to support the Gateway at the completion of the demonstration**
- **Promotes the development of commercial applications of PPE technologies**

Public/Private Partnership

- **NASA is increasingly relying on public-private partnerships that simultaneously stimulate U.S. commercial space industry while delivering NASA mission capabilities at lower costs**
- **Demonstrating advanced SEP onboard a commercially-derived spacecraft bus aligns with U.S. industry needs and provides NASA a capability suitable for use as the first Gateway element**
- **Offerors will propose a partnering and commercial approach based on their specific targeted follow-on commercial applications that advance U.S. industries competitiveness**
- **The profit potential of these future products establishes the basis for shared risk in the development and demonstration of PPE**
- **Offerors' proposals will address their commitment to the public/private partnership by identifying:**
  - Commitment of Offeror's corporate resources
  - The profit potential of the proposed future PPE-derived products
  - How proposed commercial objectives are achieved by the demonstration
  - Capabilities identified by the Offeror, as required by their specific objectives, are at the Offerors expense and considered a corporate contribution

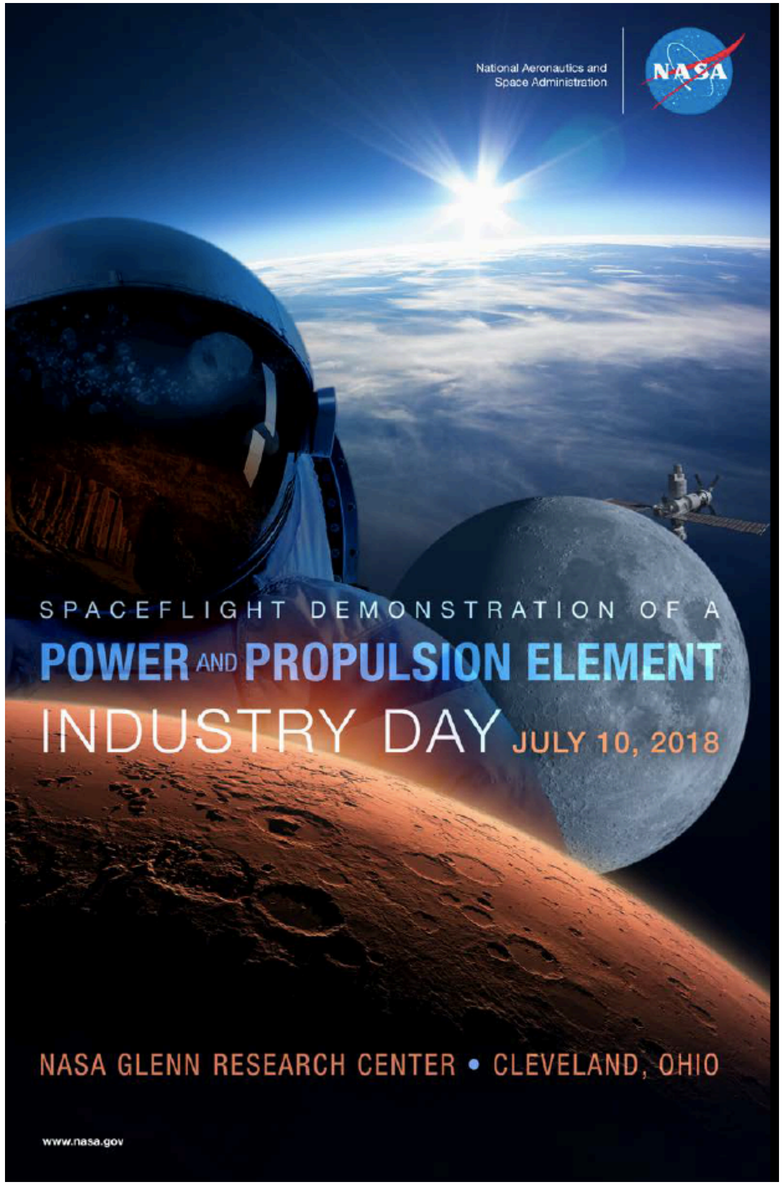
BAA Partnership Considerations

- **Various aspects of the BAA were specifically designed to enable a public/private partnership while simultaneously allowing NASA the option to own and use the PPE after completion of the demonstration**

- **NASA plans to leverage industry designs and the proven reliability of commercial spacecraft by employing a reliability-based approach to PPE certification that:**
  - Minimizes changes to existing industry designs and construction methods and use industry standards and processes to retain demonstrated reliability benefits
  - Establishes operational boundaries based on demonstrated flight-system performance data
  - Relies on a robust industry safety program that includes a stringent quality assurance program based on industry supplied data for safety hazards, system reliability, qualification test and analysis data including a design and development test program to augment flight reliability data as necessary

- **NASA is committing to stable requirements, minimizing requirement changes, streamlined reporting, and an insight-only approach to contract management focused on understanding risk**

PPE Industry Day – July 10, 2018



- Many of the Industry participants expressed their appreciation for a high quality DBAA and a very productive and useful Industry Day event.

- Overall industry feedback to DBAA was very positive and will help PPE finalize its approach.

- Written industry comments to DBAA were submitted on July 20.

AGENDA

9:00 a.m.	Kickoff—Industry Day objectives and guidance
9:15 a.m.	Welcome from GRC Center Director
9:25 a.m.	Comments from PPE Director
9:40 a.m.	PPE Manager overview
9:55 a.m.	Export Control—International Traffic in Arms Regulations (ITAR) guidance
10:00 a.m.	PPE DBAA overview
10:30 a.m.	Break
10:45 a.m.	Response to questions
11:00 a.m.	PPE DBAA overview (continued)
11:40 a.m.	Response to questions and morning wrap-up
12:00 p.m.	Lunch break, Cafeteria, Building 15
1:00 p.m.	PPE DBAA overview (continued)
1:30 p.m.	Government Task Agreement (GTA) overview
1:45 p.m.	NASA GTA Points of Contact (POC) briefings
2:30 p.m.	Break
2:45 p.m.	NASA GTA POC briefings (continued)
3:00 p.m.	Presentation on Advanced Electric Propulsion System
3:15 p.m.	Questions posed to Industry—key dates
3:45 p.m.	Response to questions and afternoon wrap-up
4:00 p.m.	Adjourn

PPE External Events - Completed

- ✓International Space Development Conference panel participation — May 24, 2018
- ✓Space Ops Conference panel participation — May 28, 2018
- ✓PPE Industry Day – GRC — July 10-12, 2018



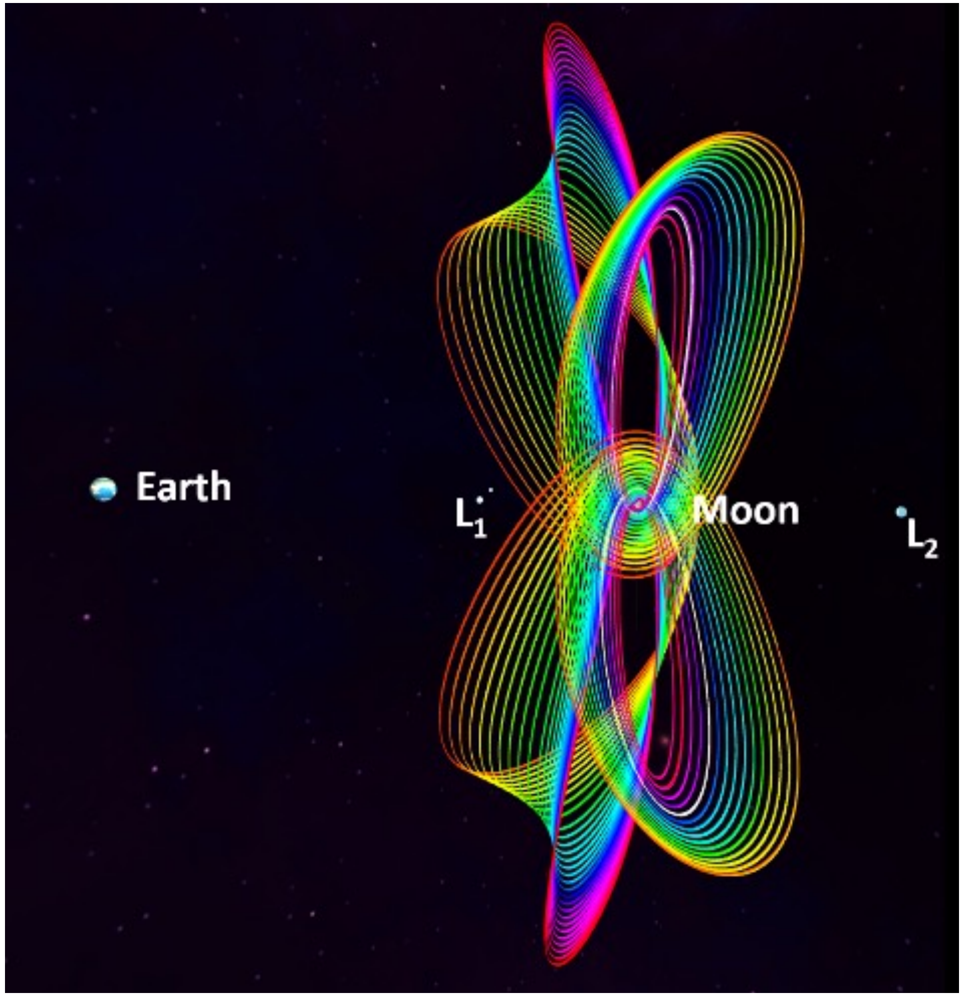


- ✓AIAA Propulsion and Energy Forum – Cincinnati, OH; July 9-11, 2018, Gateway Power and Propulsion Element Studies Panel

- ✓2018 AAS/AIAA Astrodynamics Specialist Conference papers' presentations — Aug 19-23, 2018

Planned Lunar Orbit for PPE Handover to NASA for Gateway Use

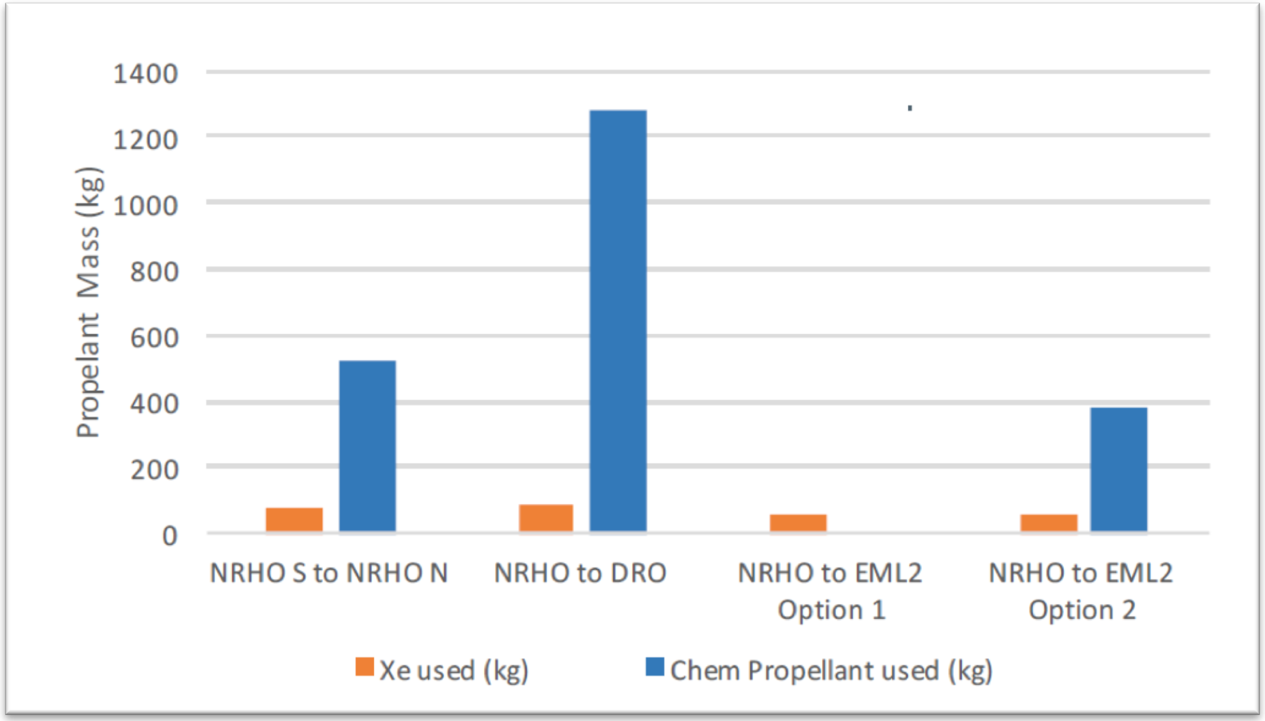
- **Orbits about the Moon can be used to support missions to the lunar surface and vicinity including as a staging point**
  - Offers long-term stable storage, coverage of lunar North and South poles, ease of access
  - Ability to avoid lengthy eclipses of the sun by the Earth, maximizing solar energy
  - Exhibits nearly-stable behavior favorable for station-keeping and nearly-constant communications contact with Earth
  - Supports surface telerobotics, including lunar farside
  - Provides a staging point for planetary sample return missions
- **Additional science**
  - Favorable vantage point for Earth, Sun and deep space observations
- **Environment**
  - Deep space environment useful for radiation testing and experiments in preparation for missions to the lunar surface and Mars



Representative L_1 and L_2 Northern and Southern NRHOs[1,2]

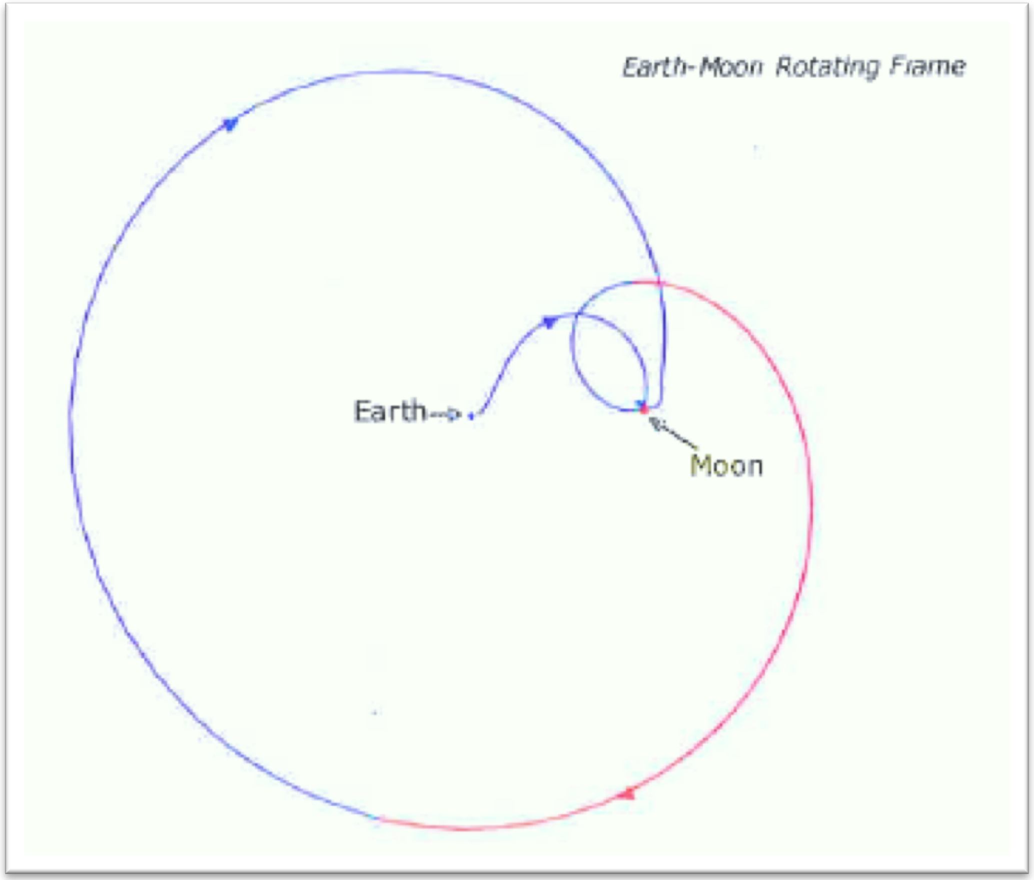
1. R. Whitley and R. Martinez, “Options for Staging Orbits in Cis-Lunar Space,” Oct. 21, 2015. IEEE Aerospace Conference; 5-12 Mar. 2016; Big Sky, MT, JSC-CN-35647
2. M. L. McGuire, L. M. Burke, S. L. McCarty, K. J. Hack, R. J. Whitley, D. C. Davis, and C. Ocampo, “Low Thrust Cis-Lunar Transfers Using a 40 KW-Class Solar Electric Propulsion Spacecraft,” *AAS/AIAA Astrodynamics Specialist Conference*, August 2017, AAS 17-583

Advantages of Solar Electric Propulsion



Representative Comparison of SEP (Xe) vs Chemical Propulsion[2]

Option 1 analysis results for chemical propellant not shown; approximates option 2.

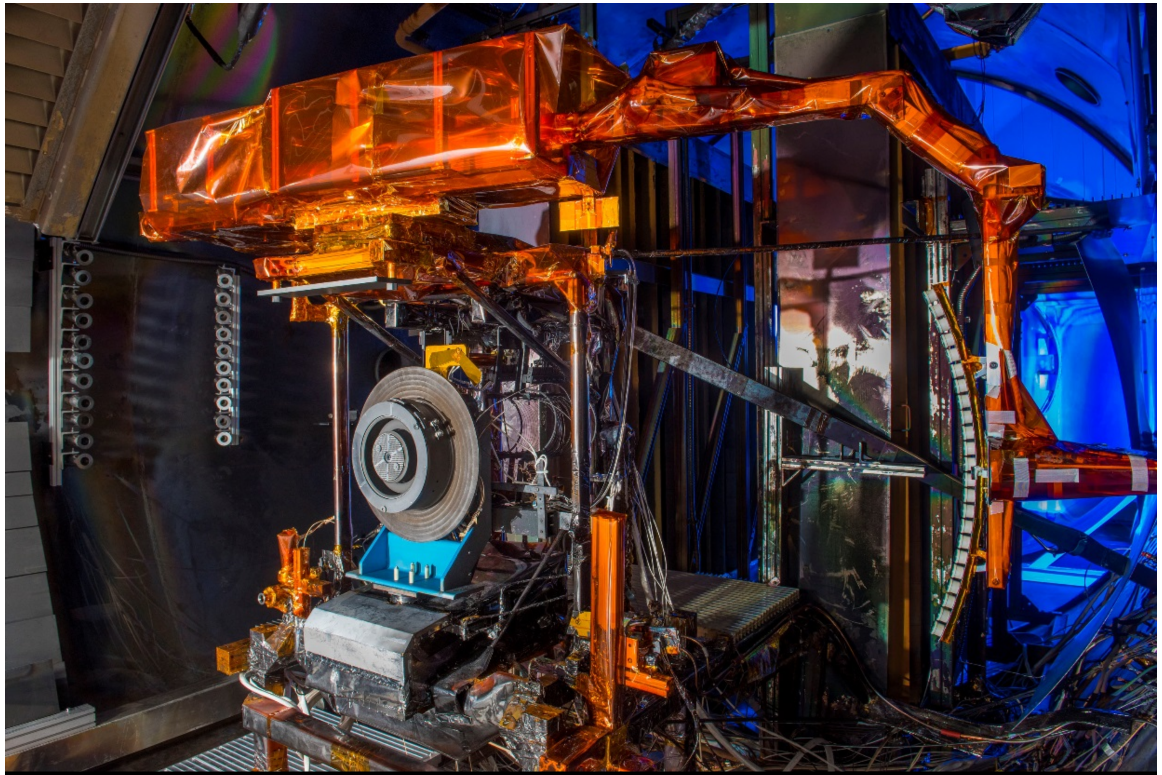


Representative 75.9-day NRHO insertion trajectory in the Earth-Moon rotating frame. Coast and thrust arcs are colored in blue and red, respectively. [3]

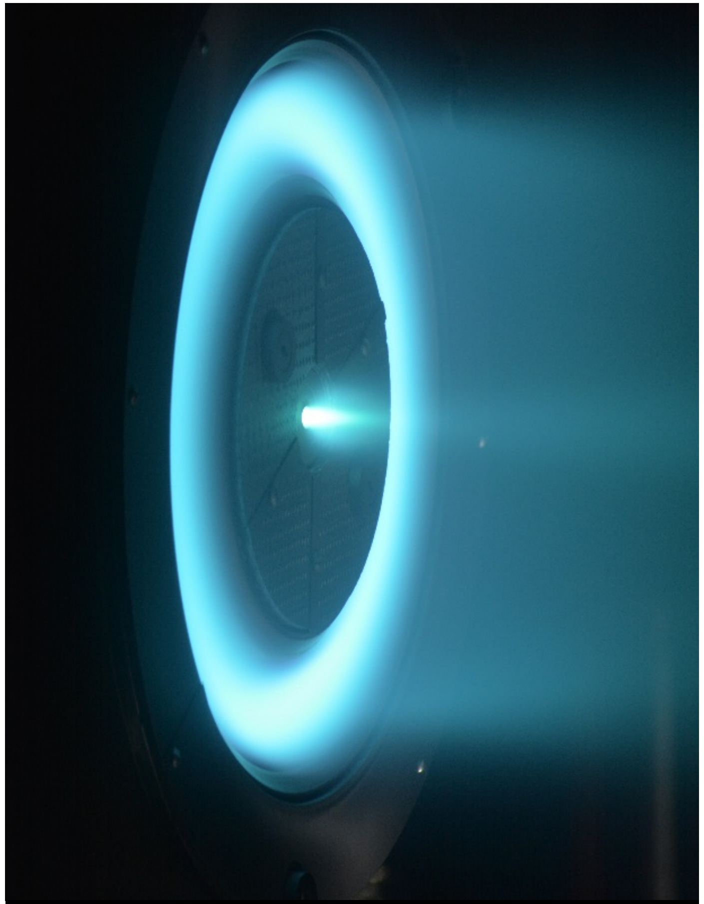
2: M. L. McGuire, L. M. Burke, S. L. McCarty, K. J. Hack, R. J. Whitley, D. C. Davis, and C. Ocampo, "Low Thrust Cis-Lunar Transfers Using a 40 KW-Class Solar Electric Propulsion Spacecraft," *AAS/AIAA Astrodynamics Specialist Conference*, August 2017, AAS 17-583

3: S. L. McCarty, W. K. Sjauw, L. M. Burke, M. L. McGuire, "Analysis of Near Rectilinear Halo Orbit Insertion with a 40 KW-Class Solar Electric Propulsion System," *AAS/AIAA Astrodynamics Specialist Conference*, August 2018, AAS 18-236

STMD* High Power, High Throughput Electric Propulsion Technology Development Progress (1/3)



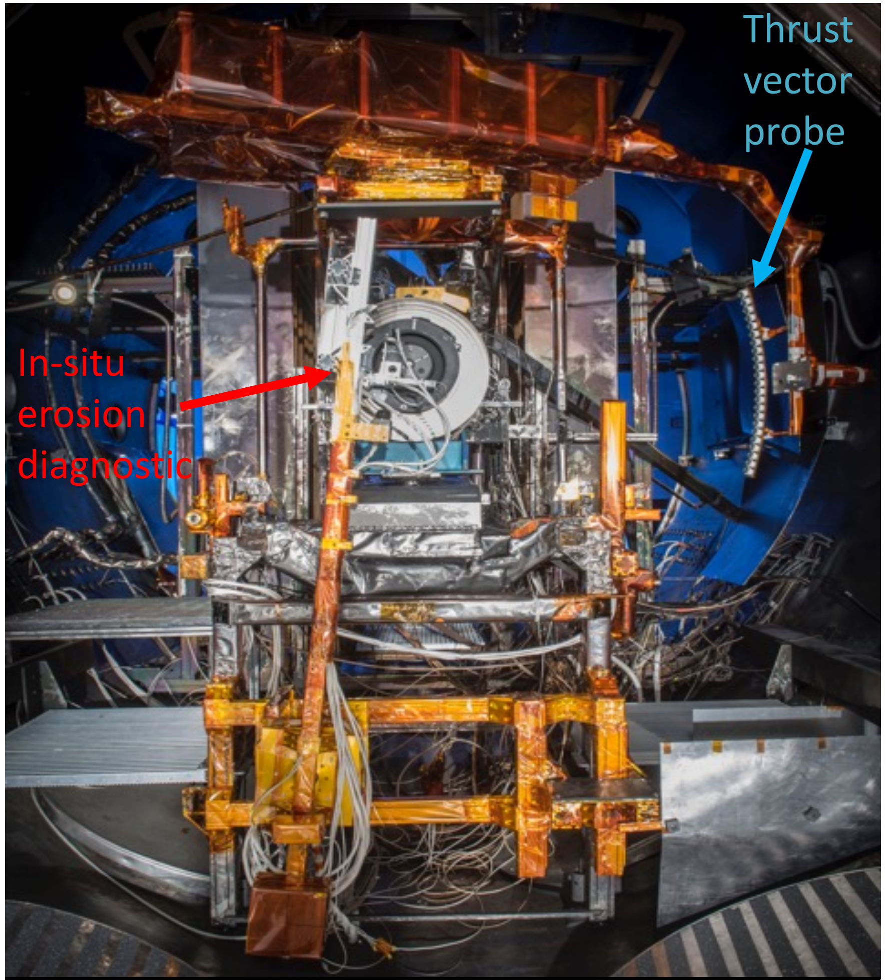
TDU-3 in Vacuum Facility - 5



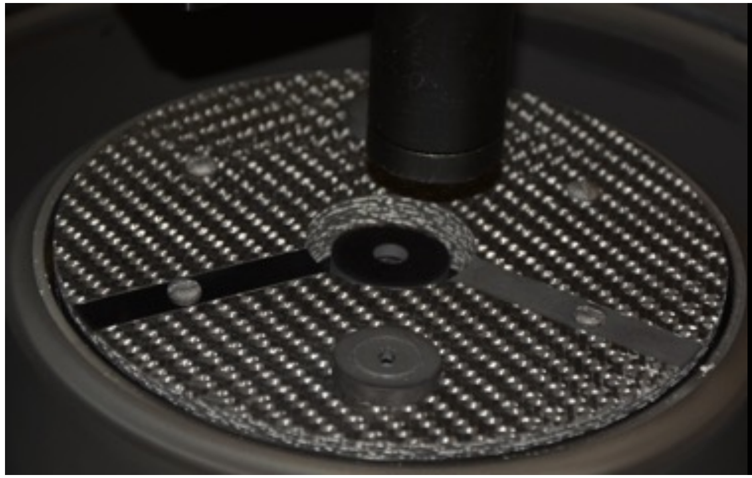
TDU-3 with Composite Inner Front Pole Cover

* Space Technology Mission Directorate

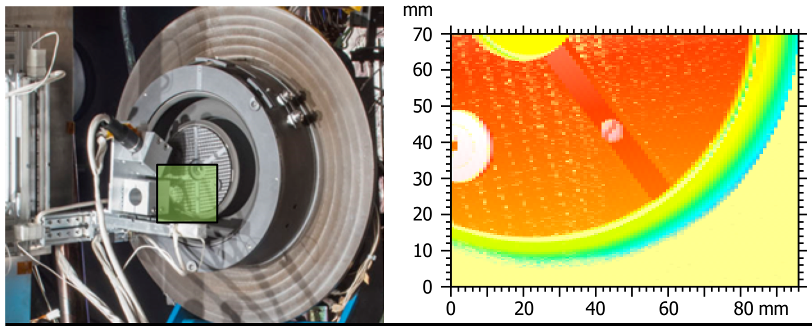
STMD High Power, High Throughput Electric Propulsion Technology Development Progress (2/3)



TDU-3 Wear Test with in-situ erosion and thrust vector probe diagnostics to support AEPS EDU thruster verifications

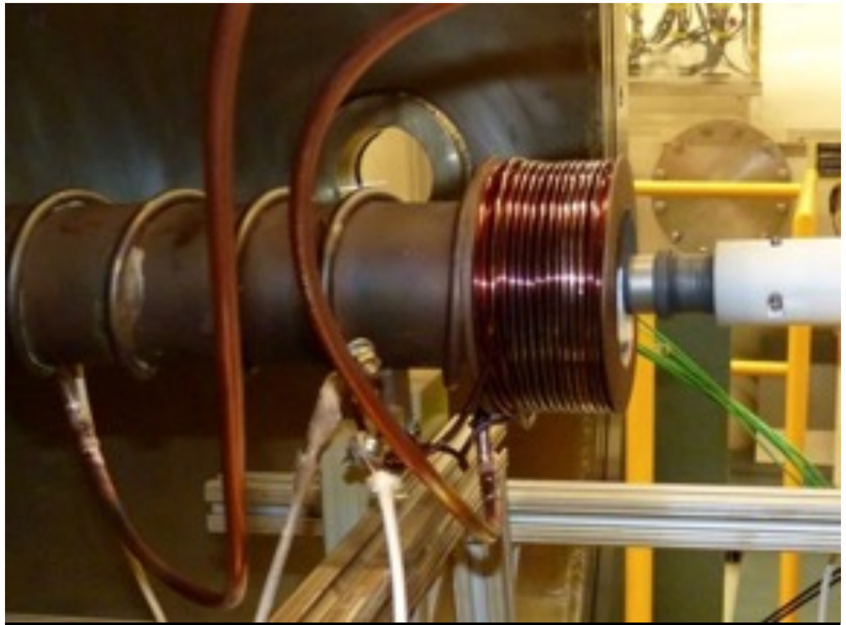


TDU-3 with composite inner front pole cover installed in profilometer. Over 3,100 total hours of life testing accumulated.

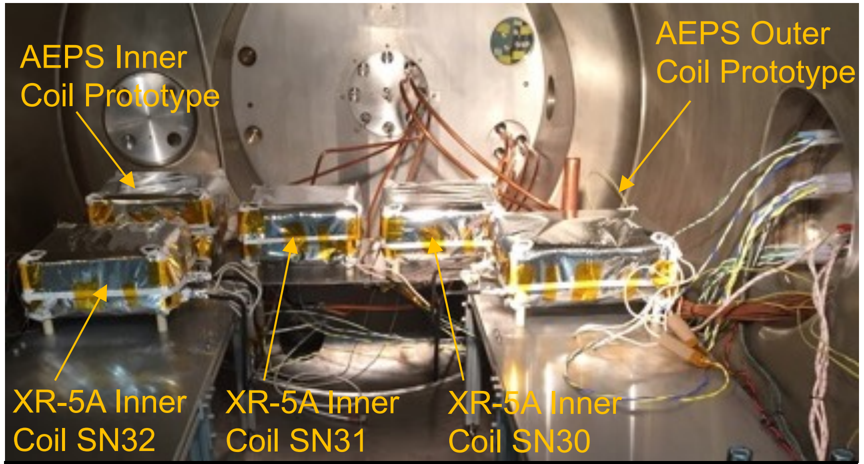


Portion of inner front pole cover being scanned in green box (left) and area scan raw data (right)

STMD High Power, High Throughput Electric Propulsion Technology Development Progress (3/3)



Lab cathode with thruster simulator anode in Vacuum Facility-56



AEPS Component and NASA Power Module Testing

PPE Upcoming Events

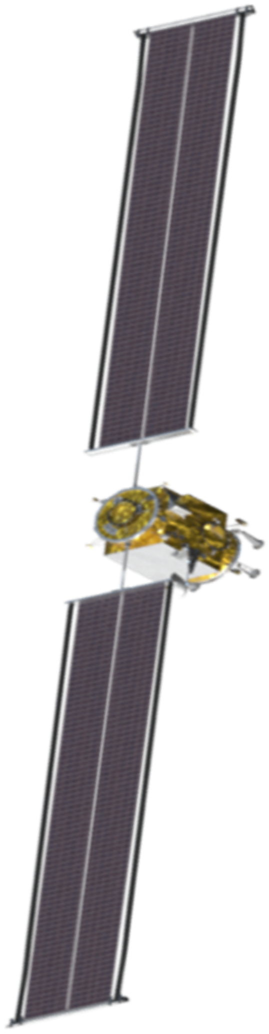
• **Final BAA released for Spaceflight Demonstration of a PPE**	**Sept 6, 2018**
• **PPE support for Gateway Formulation Sync Review Kickoff**	**Sept 11-13, 2018**
• **AIAA Space Forum panel participation**	**Sept 18, 2018**
• **International Astronautical Congress 2018 PPE status presentation**	**Oct 1, 2018**
• **Proposals to Final PPE Solicitation due**	**Nov 2018**
• **PPE partnership contract selection**	**March 2019**

NASA

Back Up

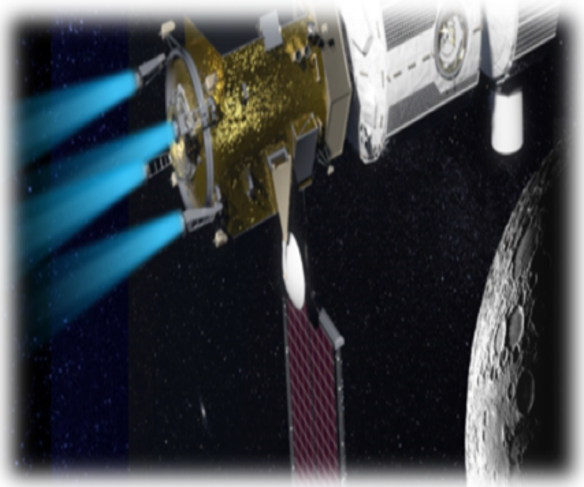
PPE NASA-Unique Spaceflight Demonstration Objectives

- Demonstrate high-power, 50kW-class solar array and electric propulsion technology in relevant space environments
- Demonstrate continuous long-term electric propulsion operation sufficient to predict the xenon throughput capability and lifetime of high power systems
- Demonstrate the deployment and successful long-term, deep- space operation of high power solar array systems with applicability to future higher power missions
- Characterize in space operation of a next generation electric propulsion string
- Demonstrate integrated SEP end-to-end system performance in relevant space environments
- Observe and characterize performance of integral high-power SEP system including thrusters, arrays, bus, and payloads as they operate as an integrated system and as they respond to the natural and induced in-space environments
- Demonstrate extended autonomous high-power SEP operations in deep space
- Demonstrate a high data throughput uplink and downlink communication system
- Demonstrate PPE insertion into a crew-accessible Near Rectilinear Halo Orbit (NRHO)
- Obtain design, development, and flight demonstration data to determine acceptability of the PPE for the Gateway



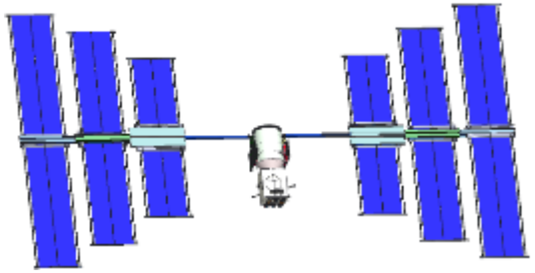
Advantages of Solar Electric Propulsion (SEP) in Cislunar Space

- **Fuel is storable, does not boil off, and can be resupplied**
- **Advanced EP provides the ability to move habitat systems to various orbits around the moon**
  - Halo, Lagrangian, or other Earth-Moon orbits
- **Analyses of in-space orbit transfers in the lunar vicinity shows a 5 to 15 fold savings in propellant with this system as compared to chemical-only systems with equivalent trip times**
- **Early use supports ensured extensibility to future Mars class transportation system**
  - Also directly applicable to a wide range of robotic and human spaceflight missions



Scalability to Higher Power Systems for Deep Space Human Exploration

- **High-power, 40-kW class system would be a step up from current technology and on the path to much higher power systems**
  - Range of powers: 150 kW to 300 kW
- **Electric propulsion technology scalable**
  - Several Hall thrusters of higher power (~50kW) have been validated in a laboratory environment
  - Power Processing Unit (PPU) design is modular
- **The solar array is scalable beyond the 90kW class with the use of additional wings.**
- **The power per thruster/PPU string is a mission dependent system-level trade between fewer higher-power strings and more numerous lower-power strings**
  - Current technology to demonstrate large scale SEP capability and performance also scales to the higher power vehicles to validate higher power generation and EP system capability in deep space



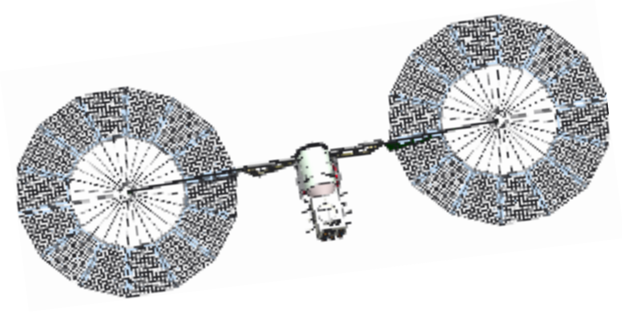


Chart reference NAC HEOC presentation July 25, 2017